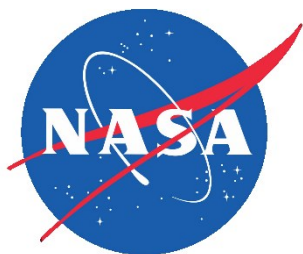




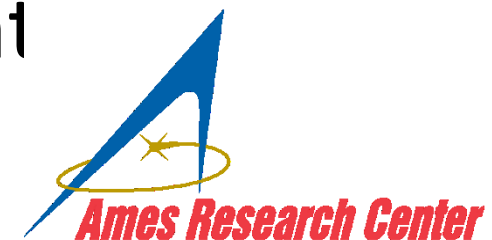
# Cockpit Hierarchical Activity Planning and Execution (CHAP-E)

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J. Benton, John Kaneshige, David Smith, Chris Plaunt, Leslie Keely, Thomas Stucky  
Dmitry Luchinsky



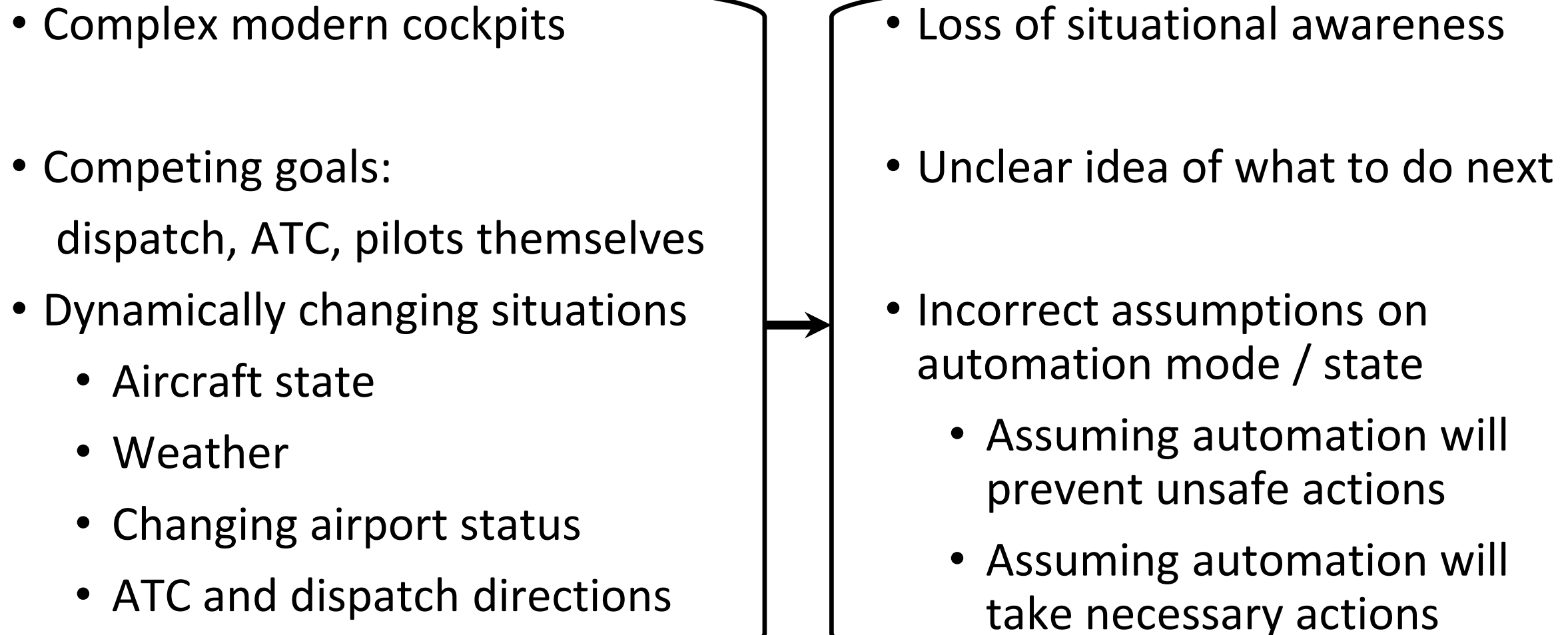
ASA Ames Research Cent





# Pilot Challenges

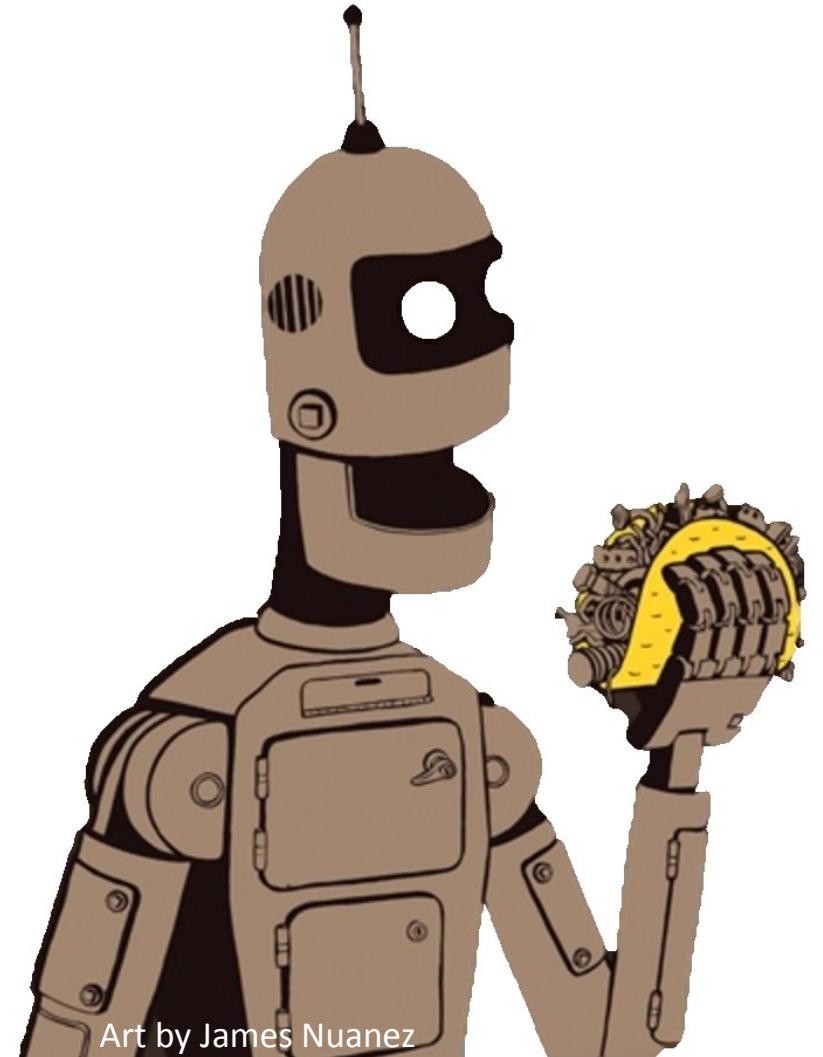
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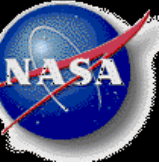


# The Meat of CHAP-E

---

- Maintain situational awareness
- Enable automated piloting assistance
- Avoid human error
- Take over flight tasks (on request)





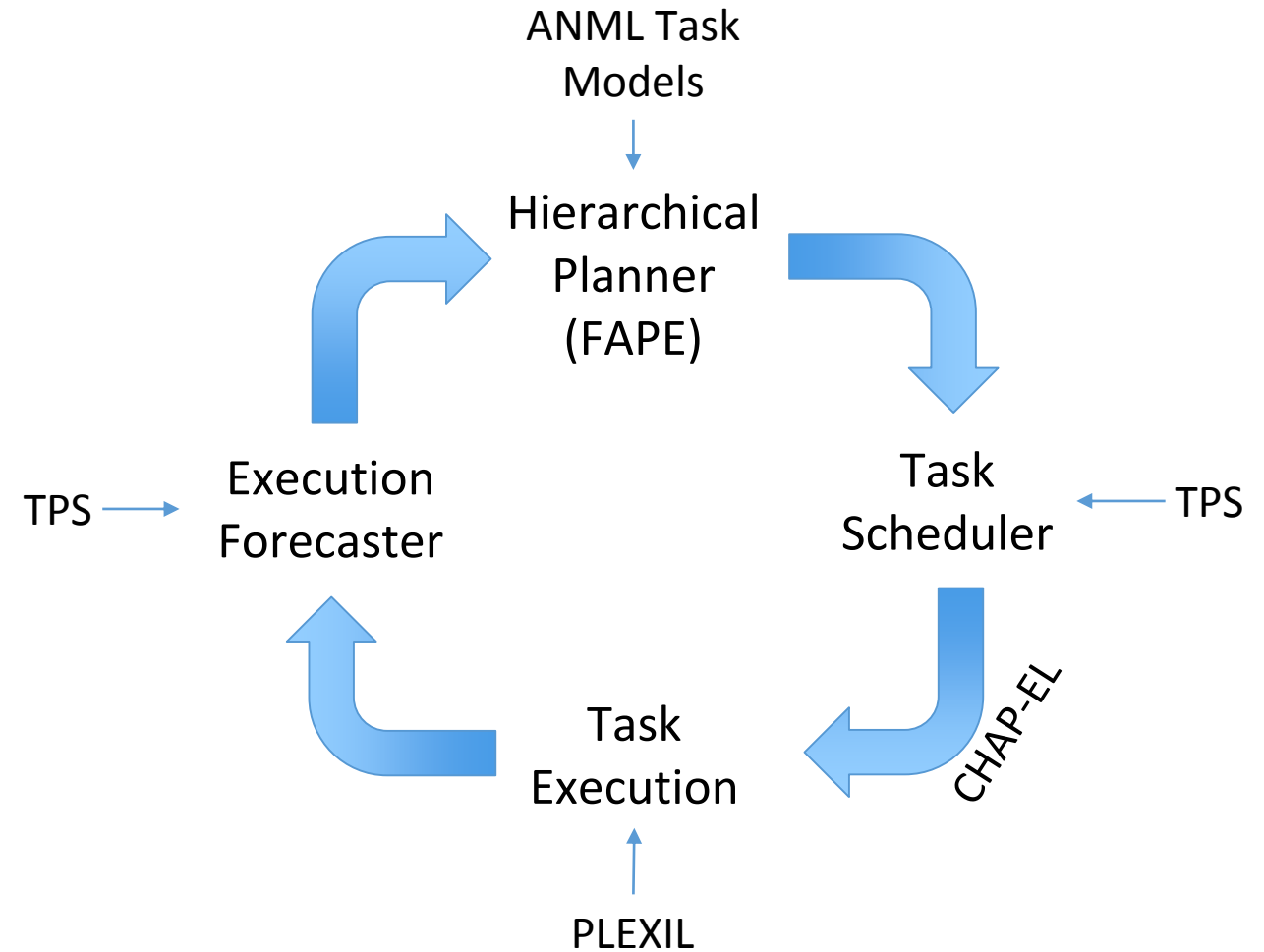
# Autonomous Flight & Decision Support

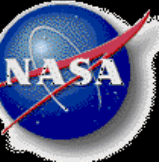
---

- Flying
  - Make critical decisions
    - Awareness of aircraft state
    - Find procedures to follow
    - Decide when to contact ATC
  - Follow flight procedures
    - Decide when to execute steps in procedure
    - Adapt flight procedures for situation
- Monitoring
  - Monitor flight situation
    - Check that pilot stays within operational limits
    - Ensure procedures followed
    - Awareness of ATC clearances
  - Monitor flight procedures
    - Monitor procedure compliance
    - Ensure procedures safely carried out

# CHAP-E Technologies

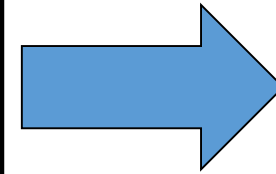
- Planning
  - ANML
  - FAPE
  - CHAP-EL
- Fast Simulation
  - TPS
- Execution
  - PLEXIL



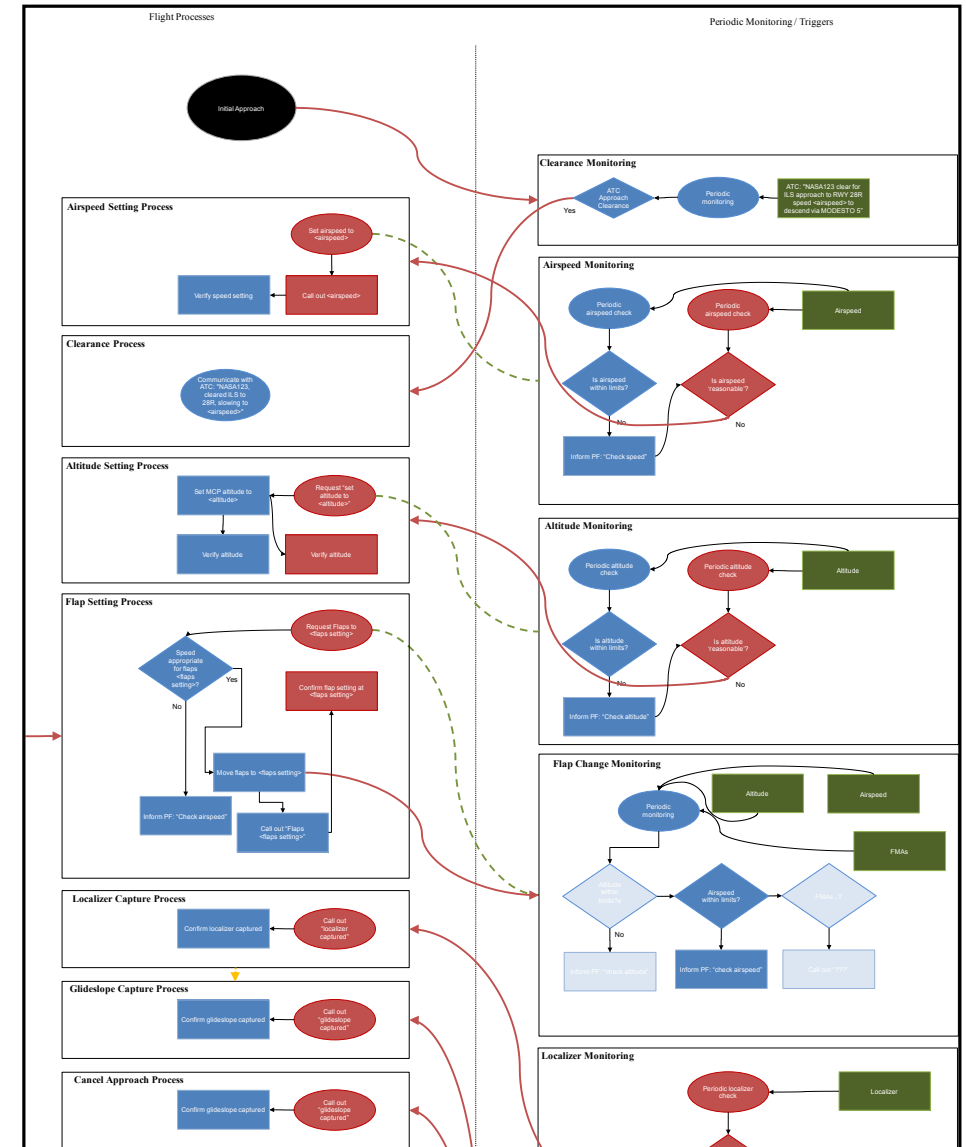


# Planning – Capture Pilot Procedures

- Standard Operating Procedures
- Carrier Flight Manuals
- Pilot Operating Handbook
- Quick Reference Guides
- Checklists
- Pilot Experience



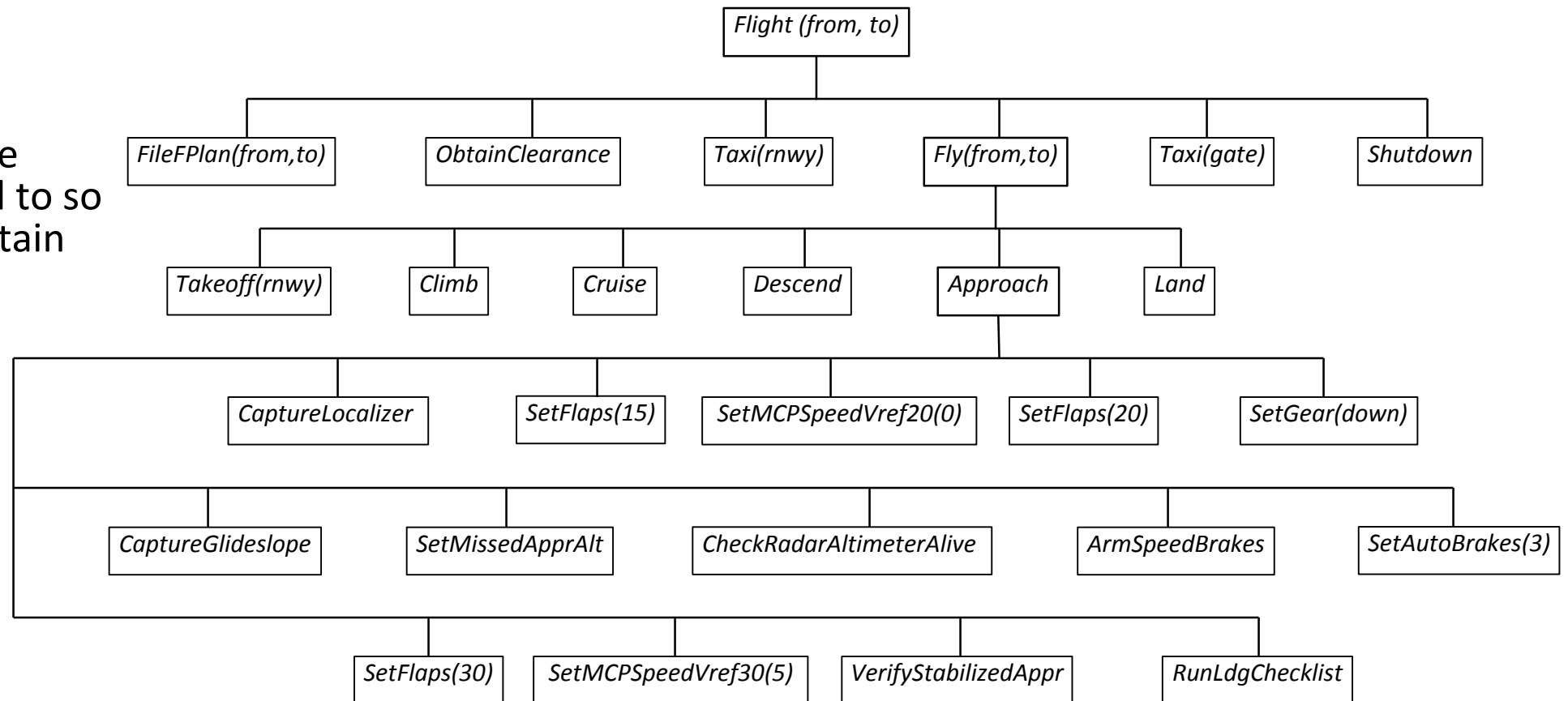
Collect  
procedures





# Planning – Hierarchical Procedures

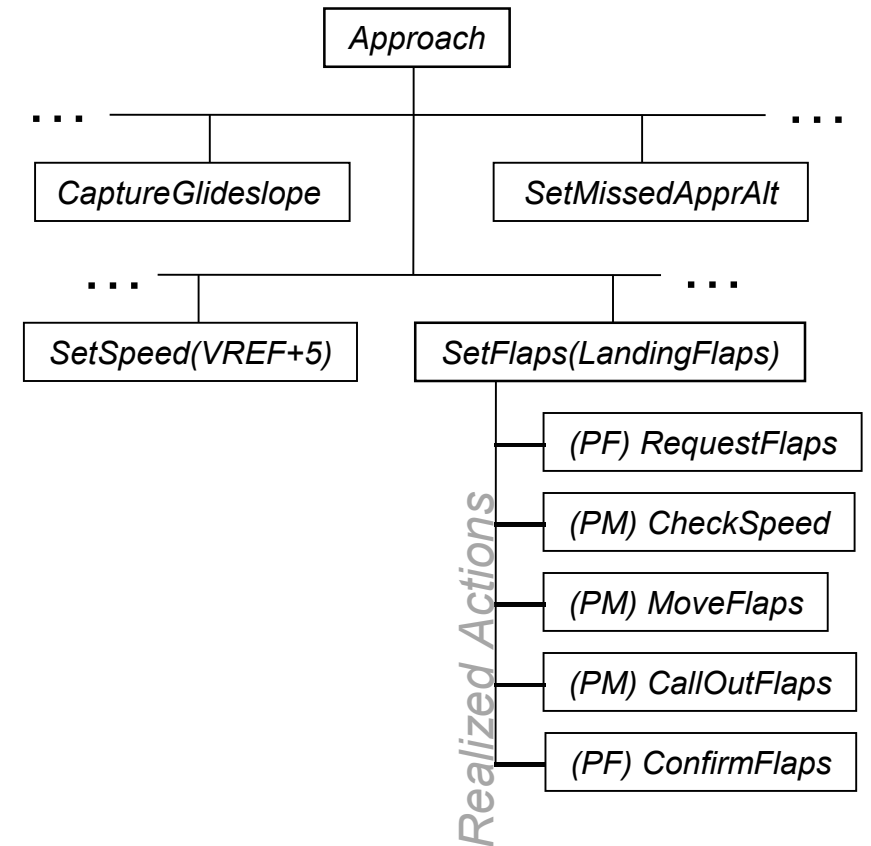
- Procedures classified into flight phases, clearances and procedures
- During flight, procedures may be modified or added to so that we may maintain flight constraints





# Planning – Hierarchical Procedures

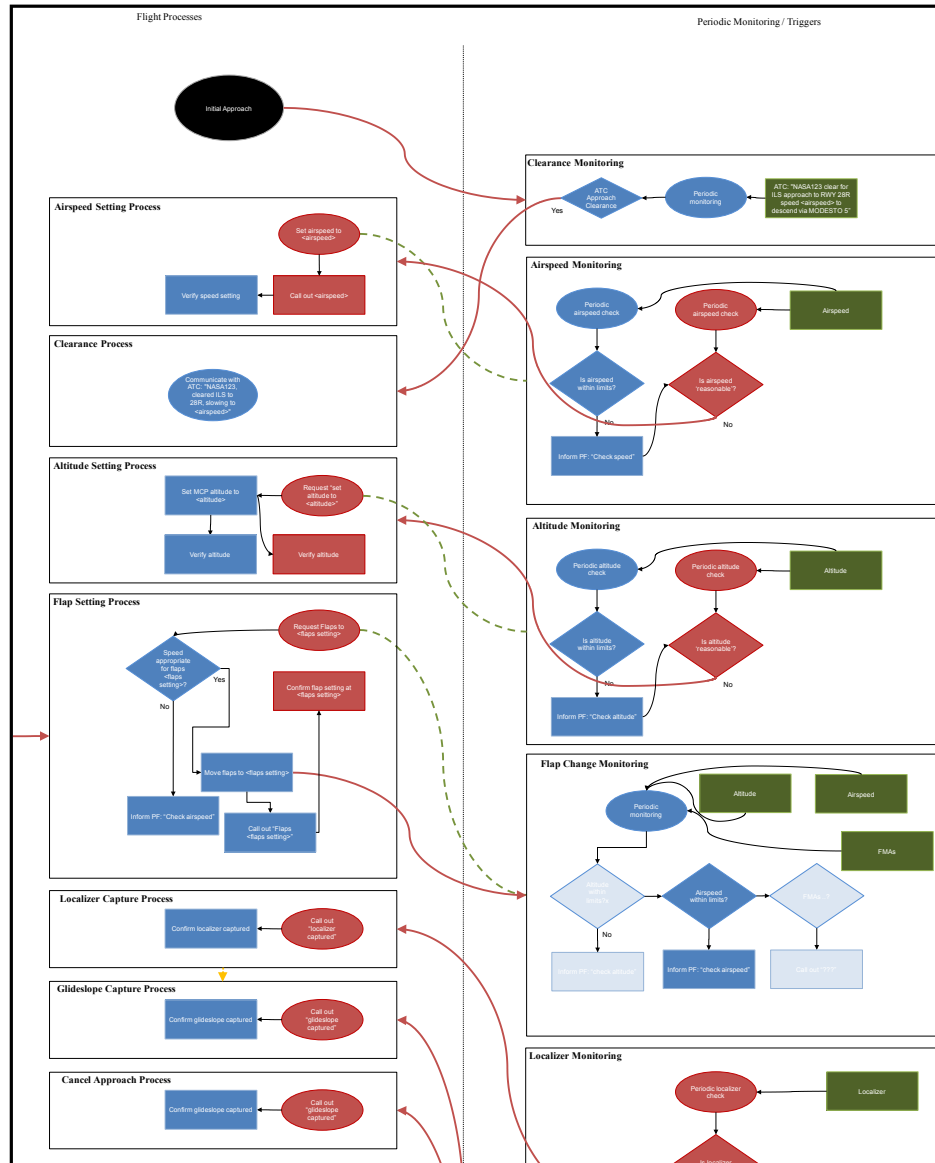
- Tasks
  - Primitive
    - Realized actions performed by pilots
  - Non-primitive
    - High-level tasks to perform
    - E.g., approach, set flaps
- Methods
  - Method T:  
Parameters: x,y  
Subtasks: T1, T2, T3, T4  
Constraints/Limitations: T1 -> T3, C -> T3
- Planner
  - Expansion of tasks using methods
  - Satisfaction of constraints



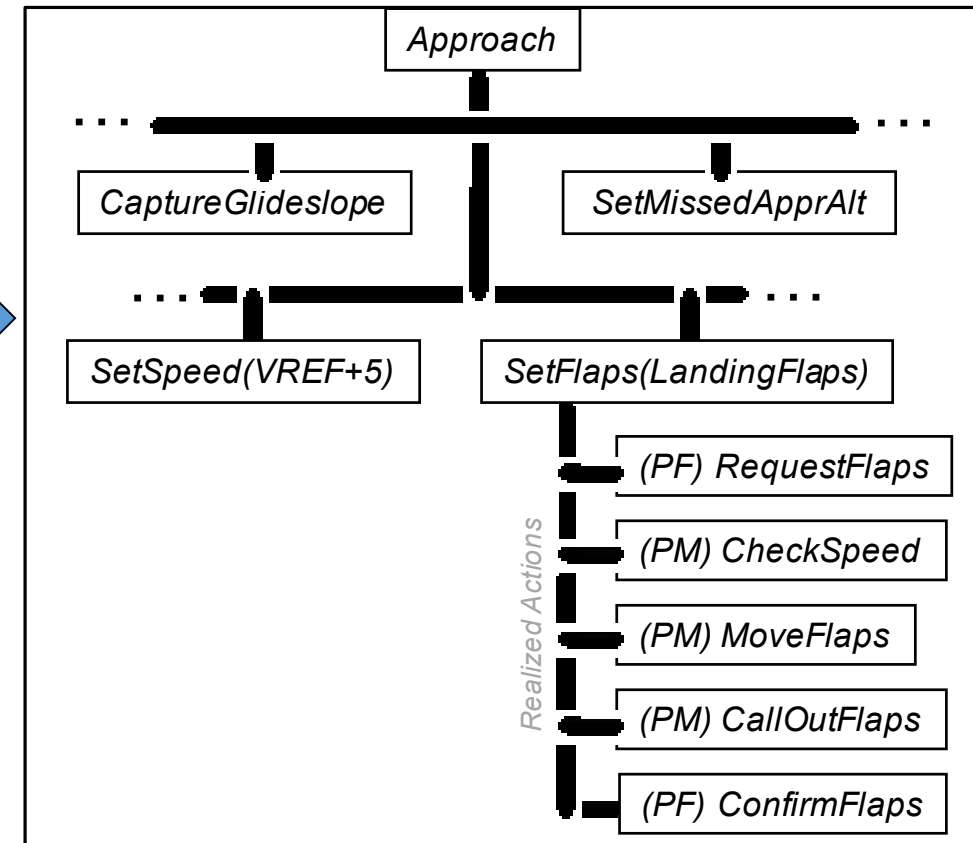




# Planning – Activity Plan Construction

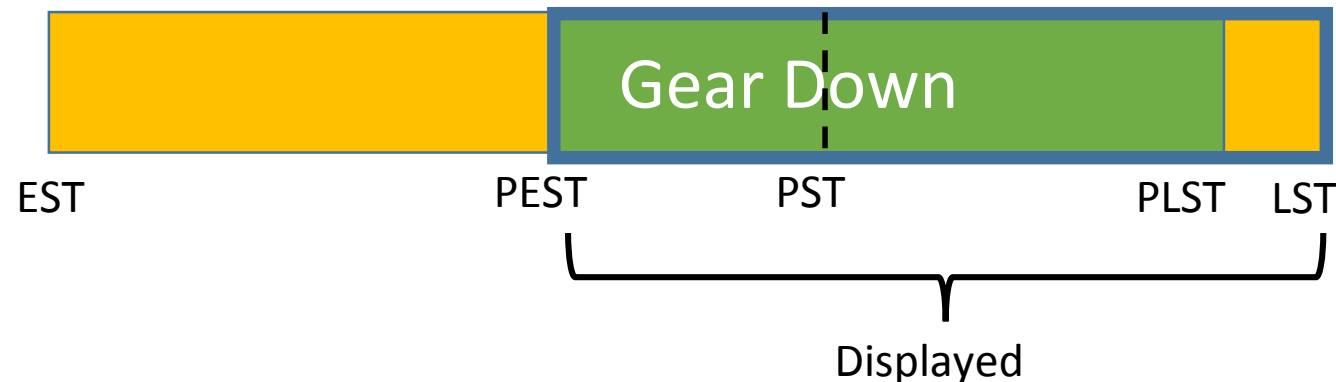


Translate to  
Hierarchy



# Scheduling - Procedure Assistance

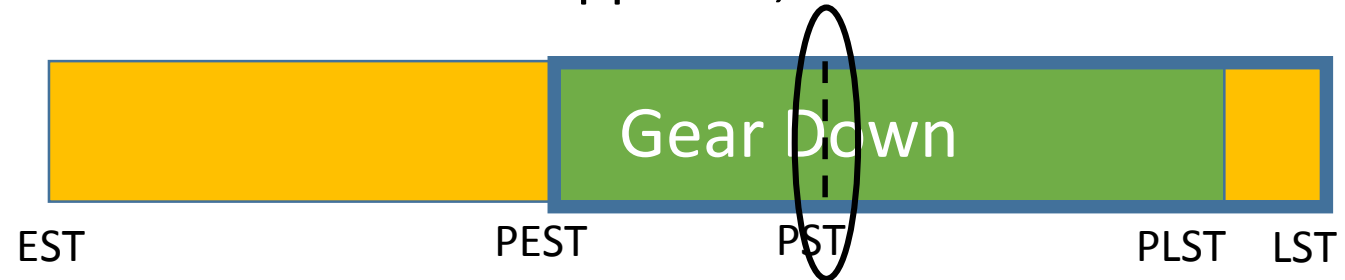
- Execution window for each action in a procedure
  - Provide estimates on best time to execute the procedure
    - Earliest Start Time (EST), Latest Start Time (LST), Preferred Earliest Start Time (PEST), Preferred Latest Start Time (PLST), Preferred Start Time (PST)
    - Defines when a pilot should perform tasks, includes exact time point
    - Automated agent performs tasks at Preferred Start Time (PST)
  - Windows found through a combination of domain modeling and fast time simulation (using TPS)



# Procedure Execution

“You have to fly before you can monitor.”

Flying: As long as all the external events happened, do this:



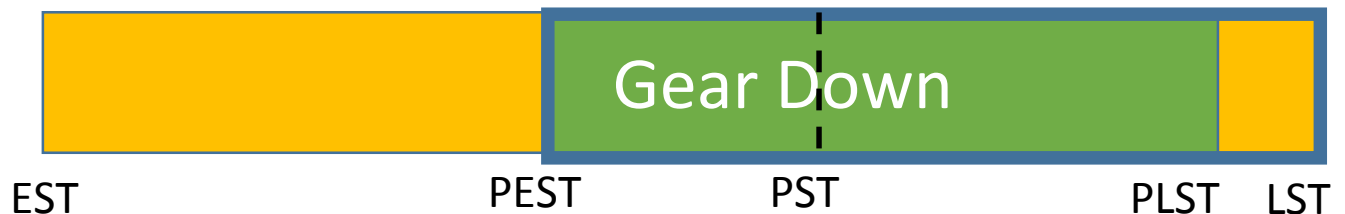
Monitoring:

Is this happening too early or late?

Did the pilots meet the constraints of this procedure?

Is this safe?

Can we still land using this procedure?





# Monitoring - Procedure Execution

CHAP-EL

- Monitor flight constraints
  - Aircraft constraints
    - $V_{max} \geq IAS \geq V_{ref}$
  - Airline operational constraints

Example: Between capturing localizer and the runway, MCP-Lmode should be LOC

Example: Stabilized approach between 1000 AGL & runway threshold
  - Procedure execution constraints

Example: After clearance, and between ARCHI and GIRRR: Arm the localizer
- Trigger re-planning if constraints violated

## Events

```
before[ARCHI-2] {CLR: start(Clearance =  
    {ClearedApproach(ILS28R.ARCHI)}}} ;  
before[ARCHI] {F5max: start(IAS <= Vmax5)} ;  
F20: start(Flaps = 20);  
A1000: start[Alt <= 1000 + TDZE) ;
```

...

## Actions

```
after[CLR] & between[ARCHI, GIRRR] {ArmLocalizer} ;  
after[CLR] & after[F5max] & between[ARCHI, GIRRR]  
    <<SetFlaps(5), SetMCP-SPD(Vref5)>> ;  
between[CLR, ARCHI] {SetMCP-Alt(1800)} ;  
after[F20] & between[AXMUL-2, AXMUL]  
    {Gear: SetGear(Down)} ;
```

...

## Monitors

```
throughout[CEDES, RW28L] IAS in [Vref,Vmax] ;  
throughout[LocCap, RW28L] MCP-LMODE = LOC ;  
throughout[CEDES, RW28R]  $V_{max} \geq IAS \geq V_{ref}$  ;  
throughout[A1000, RW28R] StabilizedApproach ;
```

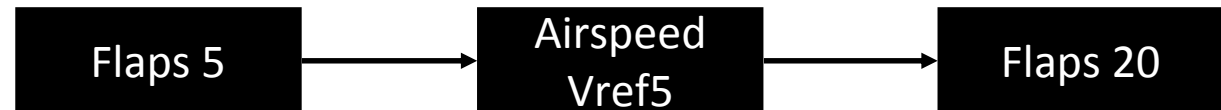


# Monitoring - Constraint Violations

Before Flaps 20  
Airspeed  $< V_{\max 20}$

Flaps 20

Procedure Segment:

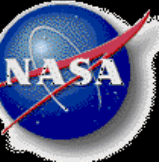


Actual Pilot Actions:



Does this violate the procedure?

No: if condition Airspeed  $< V_{\max 20}$  satisfied by  $V_{\text{ref}5+10}$



# Monitoring - Constraint Violations

Before Flaps 20  
Airspeed <  $V_{max20}$

Flaps 20

Procedure Segment:

Flaps 5

Airspeed  
 $V_{ref5}$

Flaps 20

Actual Pilot Actions:

Flaps 5

Airspeed  
 $V_{ref5+10}$

Flaps 15

Airspeed  
 $V_{ref15}$

Flaps 20

Does this violate the procedure?

No: if condition  $\text{Airspeed} < V_{max15}$  satisfied by  $V_{ref5+10}$   
& condition  $\text{Airspeed} < V_{max20}$  satisfied by  $V_{ref15}$



# Monitoring – New External Events

Before Flaps 20  
Airspeed < Vmax20

Flaps 20

Procedure Segment:

Alt 1800

Flaps 5

Airspeed  
Vref5

Flaps 20

New Event:

New Clr: Maintain  
Alt until GIRRR

Is the procedure still valid?

New Procedure  
Segment:  
(after GIRRR)

Alt 1800

Flaps 5

Airspeed  
Vref5

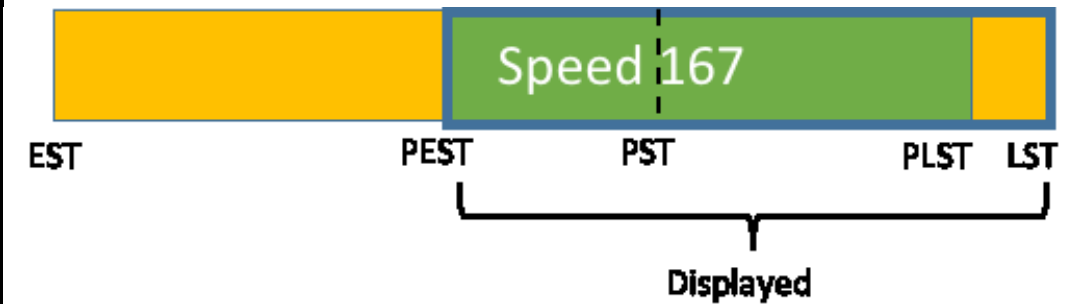
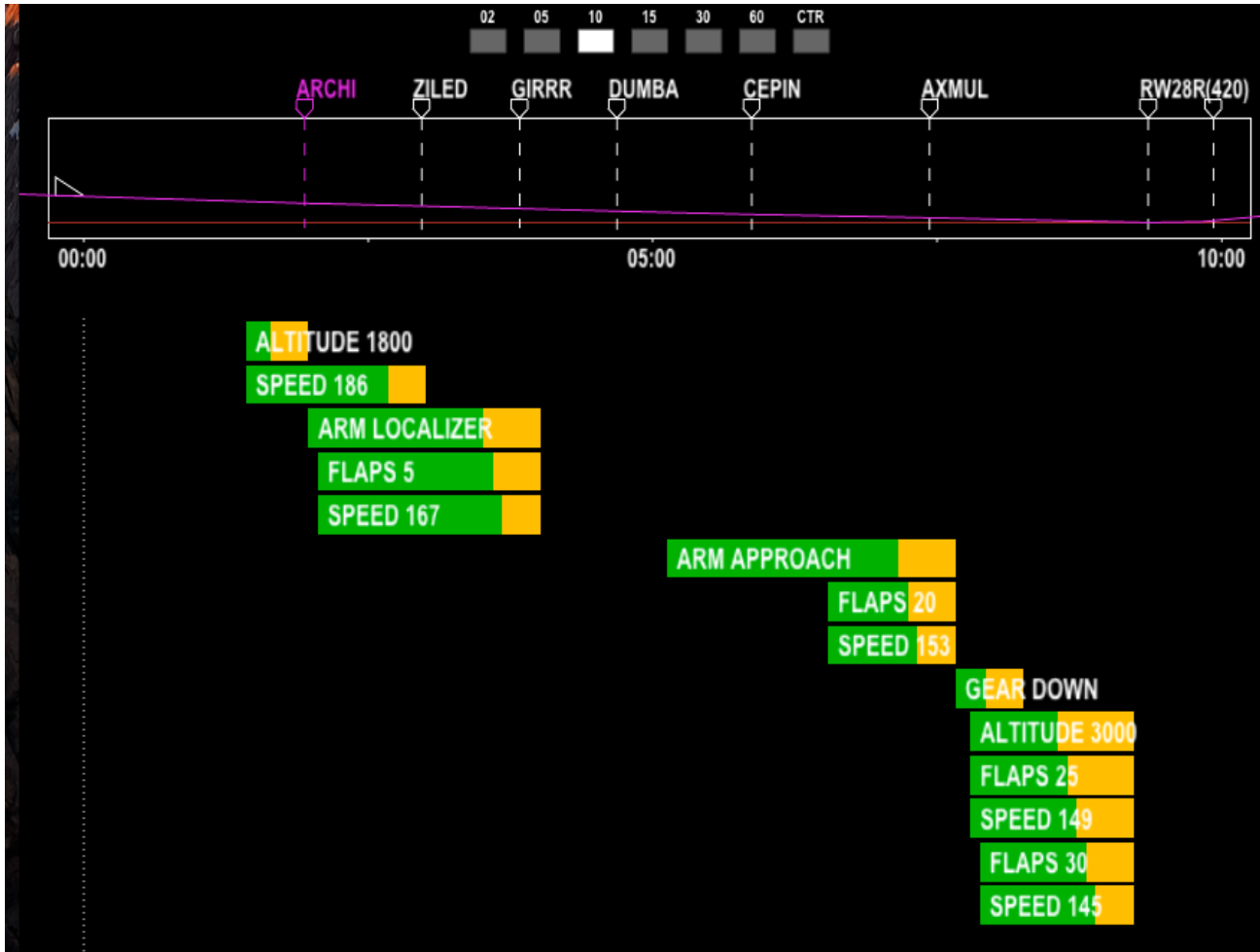
Speedbrakes

Flaps 20

Insert to  
maintain procedure



# CHAP-E Display





# CHAP-E Flying / Monitoring

MCP

A/P

F/D ON

OFF

A/T ARM

CLB CON

OFF

IAS

MACH

LNAV

VNAV

FLCH

HDG

TRK

V/S

FPA

ALTITUDE

A/P

HDG

245

VS

HOLD

LOC

APP

F/D ON

OFF

A/T

DISENGAGE

HOLD

VS

HOLD

LOC

APP

F/D ON

OFF

NDP 0

DISPLAY RANGE NM

10

20

40

80

160

320

NAV MODE

VOR

ILS

MAP

VSD

SPD

PLAN

EXP

FULL

DISPLAY SYMBOLOGY

NAV

ARPT

RTE

WYPT

WXR

TRFC

CDU 0

ACT

RTE

1

LEGS

1 / 3

0°

ARCHI

261°

ZILED

261°

GIRRR

261°

DUMBA

284°

CEPIN

8 NM

230 / 7000

3 NM

230 / 6000A

3 NM

230 / 5000A

3 NM

230 / 4000A

4 NM

179 / 3000A

RTE DATA>

PFD 0

IDLE

LNAV

VNAV PTH

230

280

260

240

220

200

180

0.41

A/P

227

9537

9900

9800

9700

9600

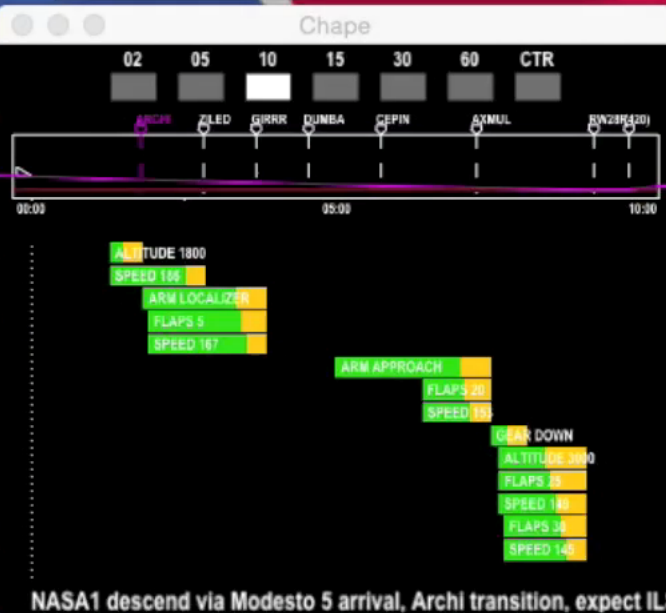
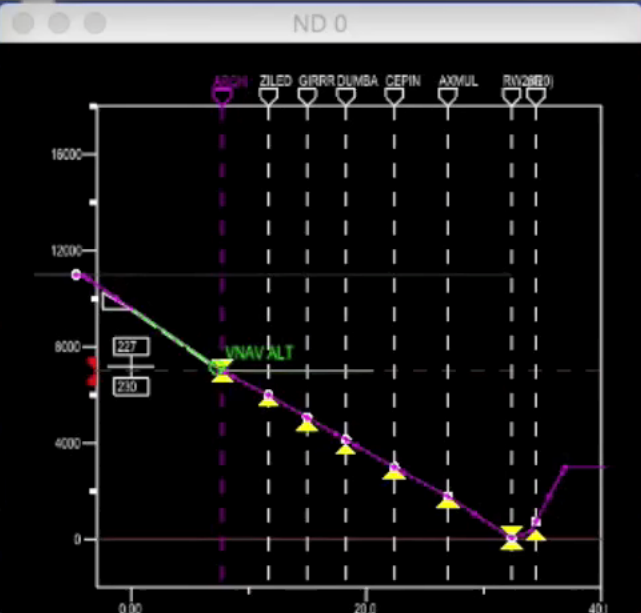
9500

9400

9300

9200

-1450



INIT REF

RTE

FMC COMM

ATC

VNAV

BRT

MENU

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DEP ARR

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CLR

Experiment Operator Station

Rec

Play

Simulation

Default

Freeze

Fast Forward

Reset

Stop

Journal acfs\_archi1 Time=1492473518732 Display=MCP Command= VNAV,1

FCP

TOGA

UP

DN

Thr...

UP

DN

G.

Speed Brake:

DN

0.0

UP

-15.0

Flaps

UP

1

5

15

20

25

30

DN

CHAP-E Monitoring

MCP

A/T ARM

IAS MACH

HDG TRK

V/S FPA

ALTITUDE

A/P

F/D ON

OFF

CLB CON

OFF

A/T

LNAV

VNAV

FLCH

A/P DISENGAGE

HOLD

VS

HOLD

LOC

APP

F/D ON

OFF

5

25

SEL

BANK LIMIT

DN

UP

AUTO

1000

ND

NDCP 0

10

20

40

80

160

320

NAV MODE

EXP VOR

FULL ILS

MAP

VSD

SPD

PLAN

DISPLAY SYMBOLOGY

NAV

ARPT

RTE

WYPT

WXR

TRFC

CDU 0

ACT

RTE 1

LEGS 1 / 3

0°

261°

261°

261°

261°

284°

ARCHI

ZILED

GIRRR

DUMBA

CEPIN

3 NM

3 NM

3 NM

3 NM

4 NM

230 / 7000

230 / 6000A

230 / 5000A

230 / 4000A

179 / 3000A

RTE DATA>

INIT REF

RTE

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VNAV

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CLR

PFD 0

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LNAV

VNAV PTH

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220

200

180

20

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7000

8500

8400

8300

8200

8100

8000

7900

7800

7700

7600

7500

7400

7300

7200

7100

7000

6900

6800

6700

6600

6500

6400

6300

6200

6100

6000

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5200

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4300

4200

4100

4000

3900

3800

3700

3600

3500

3400

3300

3200

3100

3000

2900

2800

2700

2600

2500

2400

2300

2200

2100

2000

1900

1800

1700

1600

1500

1400

1300

1200

1100

1000

900

800

700

600

500

400

300

200

100

0

8143

-1400

24

25

26

27

28

29

30

Chape

02

05

10

15

30

60

CTR

02:30

06:00

09:30

12:30

CEDES

ARCHI

ZILED

ALTITUDE 1800

SPEED 186

ARM LOCALIZER

FLAPS 5

SPEED 167

Experiment Operator Station

Rec

Play

Fast Forward

Reset

Stop

Simulation

Default

Freeze

Fast Forward

Reset

Stop

Journal acfs\_archi1 Time=1492474153063 Display=MCP Command= VNAV,1

FCP

Thr...

G.

Flaps

TOGA

UP

DN

Speed Brake:

DN

UP

0.0

-15.0

Flaps:

UP

1

5

15

20

25

30

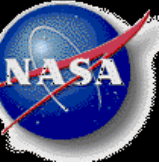
NASA1 descend via Modesto 5 arrival, Archi transition, expect ILS

# Summary

---

- Maintains situational awareness
  - Aware of instruments
  - Clearances (data comm)
- Enables automated pilot assistance
  - Suggests procedures based on situation
  - Gives safety margins on procedure execution steps
- Avoids human error
  - Warns prior to missed steps
  - Missed steps will cause procedure re-planning
- Takes over flight tasks
  - Performs suggested procedures





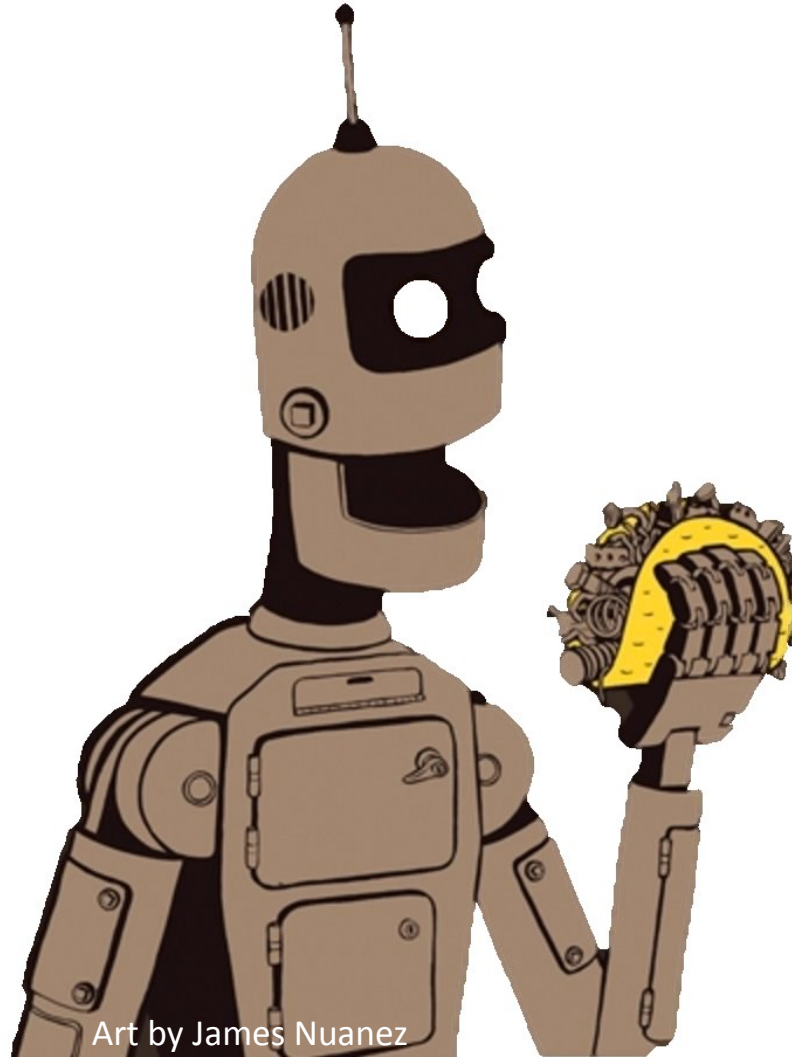
# In Progress

---

- More accurate, detailed modeling of preference windows & constraints
- Continuous Re-scheduling
  - Through fast-simulation, continuously re-schedule - execution windows may shrink, grow, or shift.
- Re-planning
  - Find new procedure when new circumstances occur or current plan is violated
- Improved tolerance of action models to handle common contingencies like speed & altitude restrictions w/out replanning
- Allow pilot to request for automated system to perform certain tasks

# Thank you

---



Art by James Nuanez





- Events

before[ARCHI-2] {CLR: start(Clearance = {ClearedApproach(ILS28R.ARCHI)}} ;

---

before[ARCHI] {F5max: start(IAS <= Vmax5)} ;

F20: start(Flaps = 20);

A1000: start[Alt <= 1000 + TDZE) ;

...

- Actions

after[CLR] & between[ARCHI, GIRRR] {ArmLocalizer} ;

after[CLR] & after[F5max] & between[ARCHI, GIRRR]

<<SetFlaps(5), SetMCP-SPD(Vref5)>> ;

between[CLR, ARCHI] {SetMCP-Alt(1800)} ; // glideslope intercept altitude

after[F20] & between[AXMUL-2, AXMUL] {Gear: SetGear(Down)} ;

...

- Monitors

throughout[CEDES, RW28L] IAS in [Vref,Vmax] ;

throughout[LocCap, RW28L] MCP-LMODE = LOC ;

throughout[CEDES, RW28R] Vmax ≥ IAS ≥ Vref ;

throughout[A1000, RW28R] StabilizedApproach ;

...

# KSFO ILS 28R

